14.—Some aspects of lateritisation in Western Australia

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Abstract

Studies of two lateritic bauxite profiles near Jarrahdale in the Darling Ranges and a third 100 miles south of this near Greenbushes, Western Australia, show that although lithologically similar, there are differences in the distribution of their mineral components. The percentage variation with increasing height in each profile for kaolinite, halloysite, gibbsite, quartz, and goethite is relatively uniform. Boehmite, however, behaves rather more erratically, for although in both the Cobiac Pit near Jarrahdale and the Angus Cut near Greenbushes it shows a proportional increase in the earthy bauxite horizon, in the main Jarrahdale opencut, the boehmite is confined to the uppermost horizon of the hardcap. The chief factors accounting for the distribution of boehmite are considered to be physiography, water table fluctuations, and vegetation cover, this being supported by additional evidence from other bauxite deposits. Heavy mineral analyses suggest that lateritisation in the higher level Jarrahdale and Cobiac Pit sections was rather more intensive than in the lower level Angus Cut section near Greenbushes indicating that topography and tectonic history were rather more important than total rainfall during bauxitisation.

Introduction

Bauxitic laterite in Western Australia, which is Tertiary in age, (Tomich 1964) forms a discontinuous surface horizon from 15 to over 40 feet thick in the Darling Ranges. This horizon increases in thickness and commercial grade from south to north over a distance of about 200 miles although its areal extent is apparently fortuitously defined by the present 25-inch isohyet.

The western boundary of this extensive Miocene laterite surface, where it adjoins the low flat Swan lowlands, is abruptly delineated by the extensive Darling Ranges thrust fault, movement along which, although initiated during the early Palaeozoic, has continued intermittently up to the present (McWhae *et al.* 1956). The laterite horizon shows extensive faulting and minor flexuring which David (1950) considers to be late Miocene and associated with epeirogenic uplift following peneplanation.

As a direct consequence of this tectonic activity, the extensive Tertiary laterite surfaces of Western Australia vary in elevation from 200 to 1,850 feet, although the higher grade gibbsitic bauxite is confined to elevations between 600 and 1,700 feet (Tomich 1964).

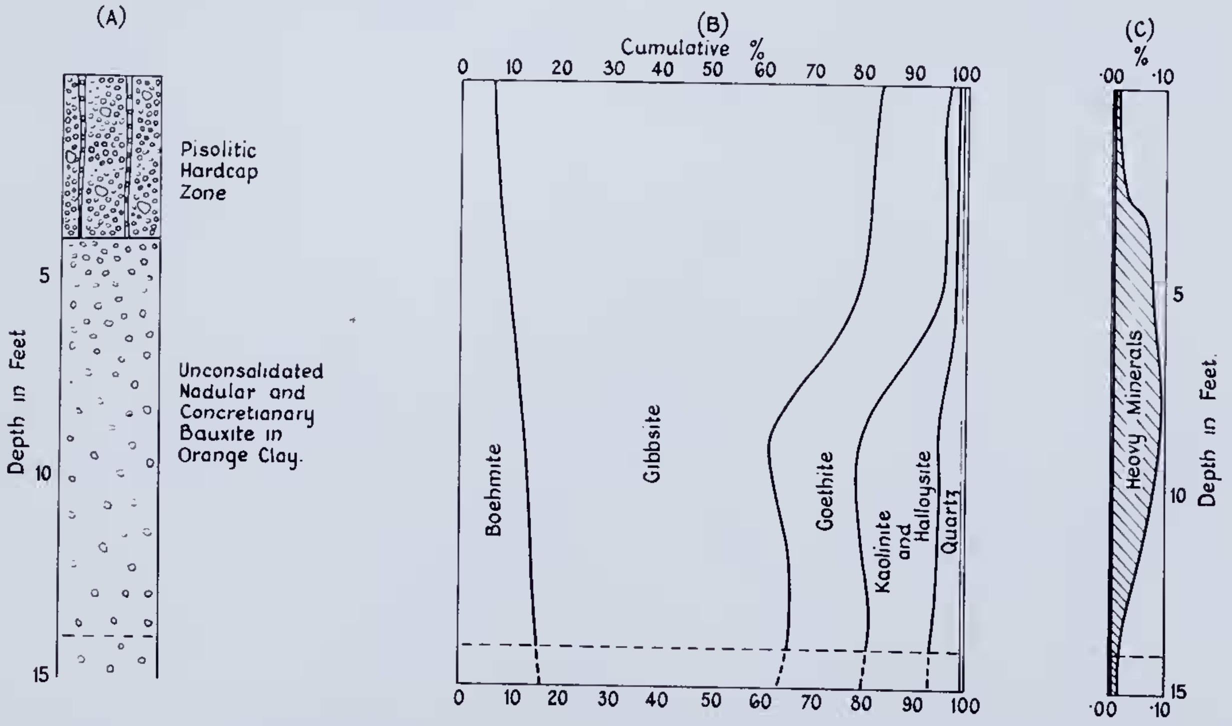

Figure 1.—Mineralogical variation with depth in the Cobiac Pit lateritic bauxite profile. (A) Lithological nature of profile, (B) Cumulative percentage by weight of the main mineral components, (C) Exaggerated diagram illustrating variation of accessory minerals with depth.

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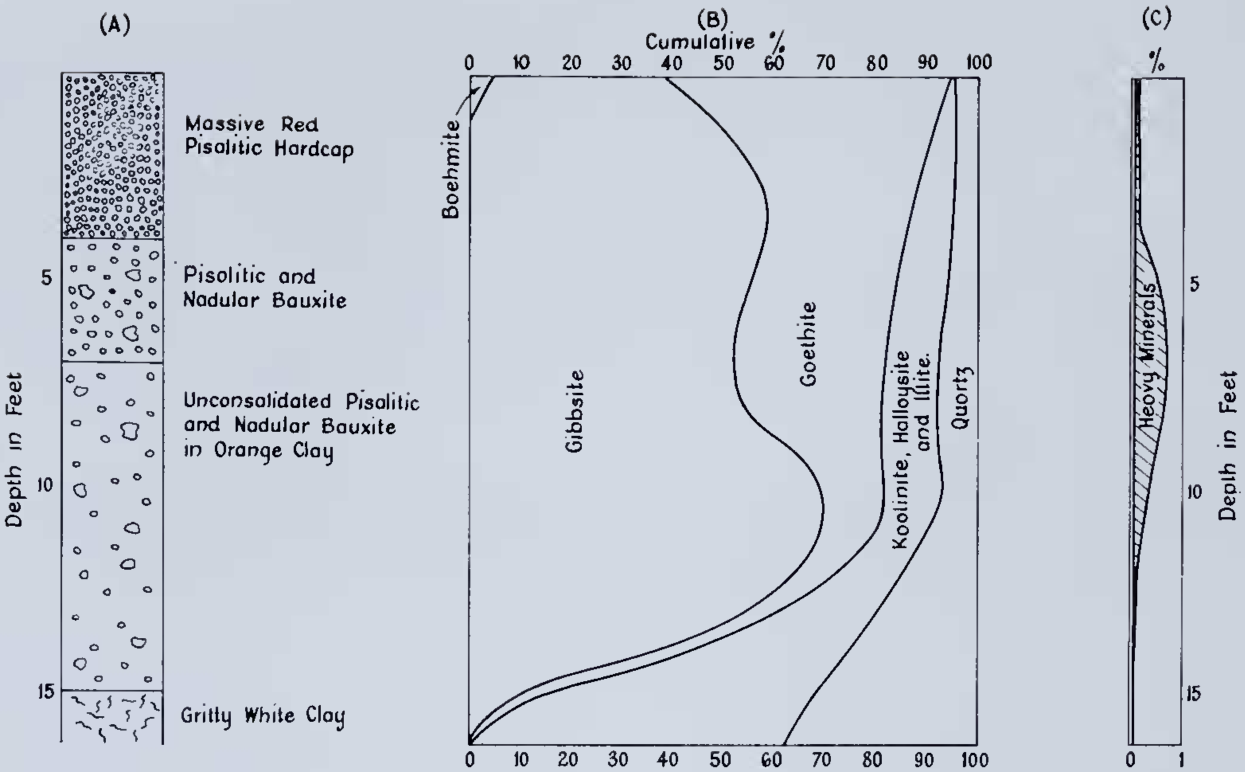

Figure 2.—Mineralogical variation with depth in the profile of the main Jarrahdale open-cut. (A) Lithological nature of profile, (B) Cumulative percentage by weight of the main mineral components, (C) Exaggerated diagram illustrating variation of accessory minerals with depth.

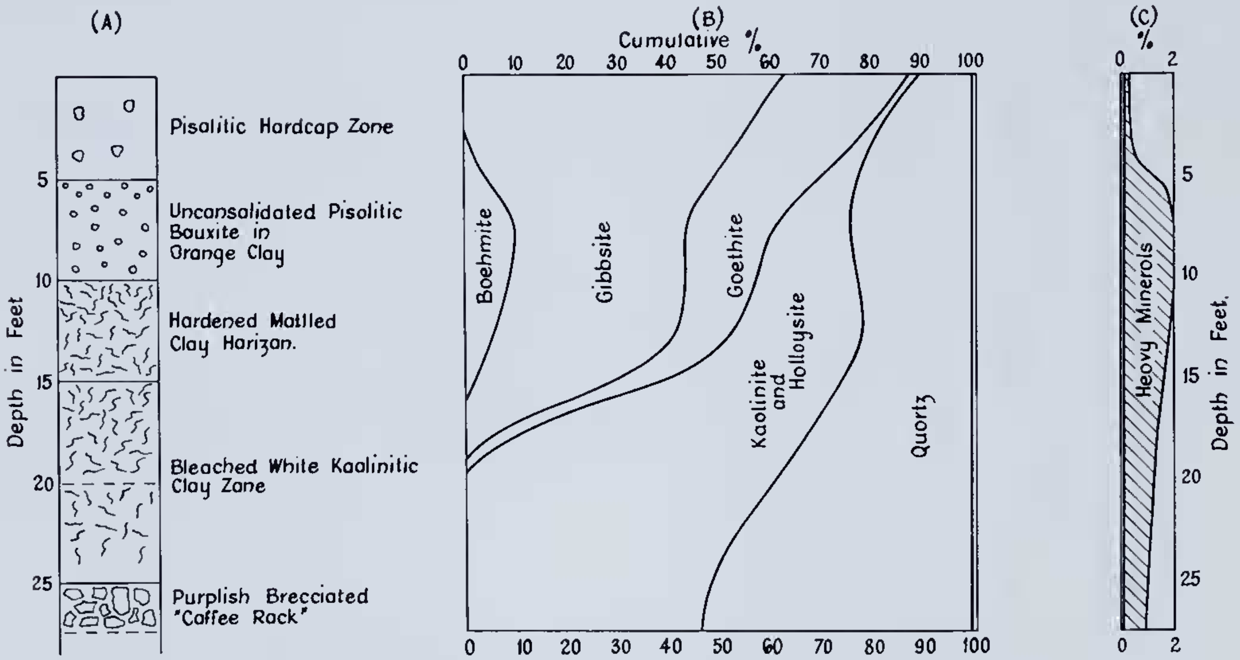

Figure 3.—Mineralogical variation with depth in the Angus Cut profile. (A) Lithological nature of profile, (B) Cumulative percentage by weight of the main mineral components, (C) Exaggerated diagram illustrating variation of accessory minerals with depth.

Field Relations

As part of an investigation into some of the compositional features of Australian bauxites, two bauxitic laterite profiles in the Cobiac Pit and main Jarrahdale opencut were examined and sampled near Jarrahdale, which is situated about 30 miles southeast of Perth. A third more siliceous type was also investigated at Angus Cut near Greenbushes, which is located about 100 miles south of Jarrahdale.

Although in field section all three profiles constitute a surface hardcap zone overlying an earthy pisolitic bauxite horizon (Figs. 1, 2 & 3), the Angus Cut profile unlike that at Jarrahdale shows an intermediate hardened mottled zone between the bleached kaolinite and earthy bauxite horizons.

The hardcap (or duricrust) is typical of that occurring over most of the continent, being pisolitic, generally ferruginous, and possessing an abundance of cavities lined by pale yellowish gibbsitic material (Figs. 4 & 5). Although for the most part irregular in shape, these sometimes (as at Gove, N.T.) form prominent pipe-like structures extending throughout the laterite profile and apparently being derived by the root action (Fig. 6).

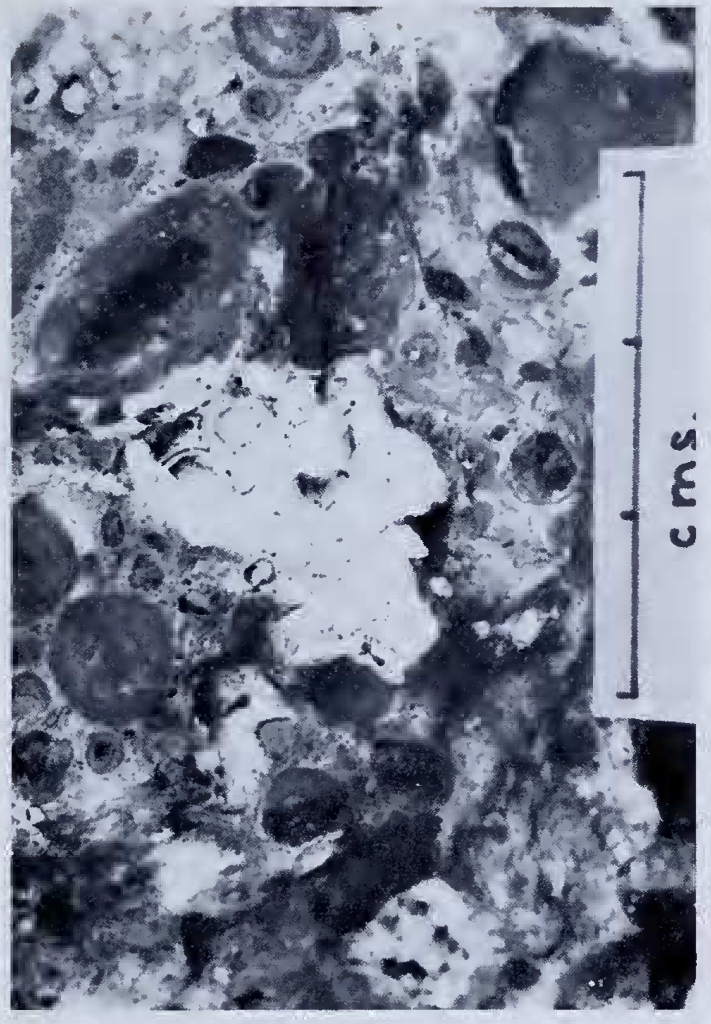

Figure 4.—Initial stages of recrystallisation and cavity formation in the hardcap at Jarrahdale.

Mineralogy

The essential mineral assemblages of the Western Australian laterites are gibbsite, boehmite, kaolinite, goethite, maghemite, metahalloysite, illite, hematite, and variable quantities of amorphous gel material.

Quantitative analyses

Accurate quantitative mineralogical analyses of bauxites are still extremely difficult to obtain even by the various techniques employed here. These complications are particularly evident in samples possessing the highest amorphous gel content. In view of this, frequent discrepancies exist in estimates derived by X-ray diffraction and chemical means. To remedy this, resort was also made to infrared, thermogravimetric, and differential thermal analysis techniques. However, the combined results obtained are still not entirely satisfactory being probably within the order of ± 10%. These results, obtained for composite samples are summarised in Figures 1, 2 & 3. They show a progressive increase in the ratios of gibbsite to kaolinite and of goethite to quartz with increasing height in each profile. The distribution of boehmite, on the other hand, although showing a corresponding increase in the Cobiac and Angus Cut profiles differs in the Jarrahdale open cut where it is confined to the uppermost 2 feet of the profile.

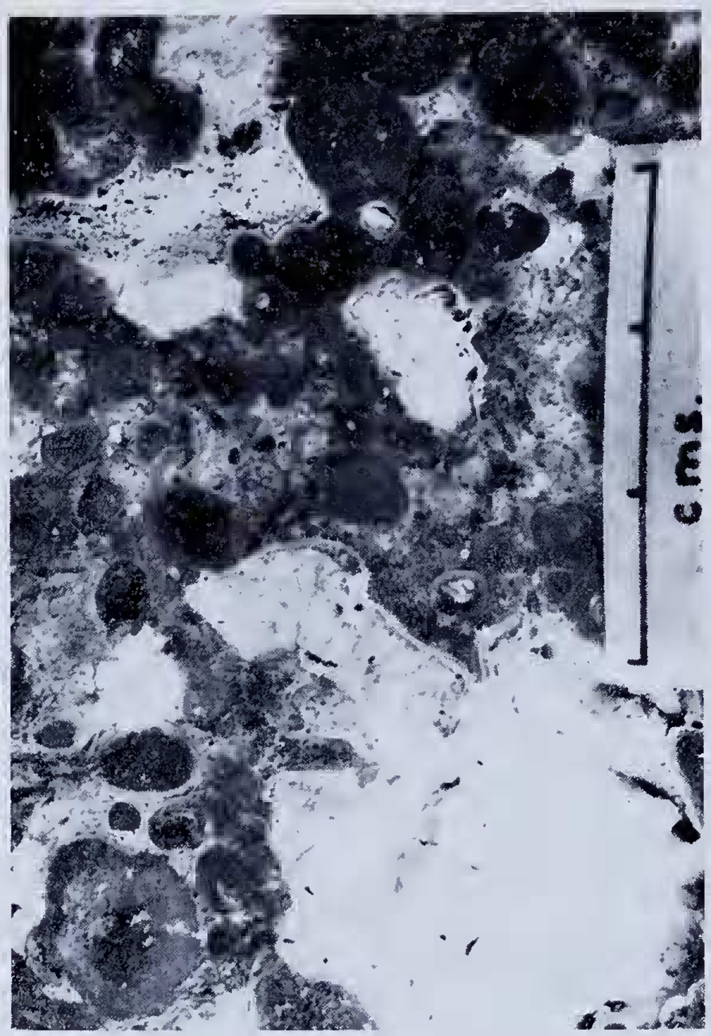

Figure 5.—Secondary cavity formation in Jarrahdale hardcap partially filled with fine gibbsitic oolites. These may subsequently be recemented by a compact boehmitic matrix.

TABLE 1

Heavy mineral analyses of the lateritic bauxite from the Darling Ranges

	Jarrahdale Opencut	Cobiac Pit	Angus' Cut
Tourmaline	X		X
Zircon	X	X	X
Zoisite	X	X	X
Leucoxene	X	X	X
Scheelite	X	X	X
Pyrite	X	X	
Topaz	X	X	
Hematite	X		
Ilmenite	X	X	
Rutile	X		
Anatase		X	
Garnet		X	
Andalusite		X	X
Cassiterite			X

X = mineral species present.

The heavy mineral constituents of these laterites (see Table 1) although quantitatively low in total per cent, nevertheless show an interesting distribution. In all three profiles they show a progressive increase with height from the basal pallid clay horizon reaching a maximum in the earthy pisolitic horizon, but thereafter decreasing sharply into the overlying pisolitic hardcap. Quantitative delineations of the total heavy mineral content in composite samples at successive levels in each laterite profile were obtained by digestion of weighed bulk samples in warm sulphuric acid followed by centrifugation to obtain the insoluble heavy fractions. Owing to the small residue weights obtained, however, individual grain counts were not practical but it is significant that in the Angus Cut section, tourmaline forms about 80 to 90% of the overall concentrate being derived directly from the underlying parent granite. For this reason it is considered the mineral fractions obtained are definitely of residual origin and that very little adventitious material exists.

Optical mineralogy

Pisolitic hardcap.—Basically, this horizon is similar in all three profiles being constituted of complexly zoned pisolites ranging from one eighth to several inches in diameter. Among these the smallest pisolites are generally the most complexly zoned and possess dark maghemite-rich cores, but the larger pisolites possess relatively fewer and broader zones enclosing cores of bauxitised parent rock (Figs. 7 & 8). As the proportion of smaller zoned pisolites tends to increase with height in each profile, it is evident that there has been a progressive physical breakup of the parent rock during bauxitisation accompanied by increased zoning of the finer fragmented particles within the horizon of maximum water table fluctuation.

Further studies of the zoning of individual pisolites by chemical and x-ray diffraction means show that apart from a regular variation in iron content, no consistent chemical or mineralogical variation exists between the thin alternating pale yellow and reddish pisolite zones, although the yellowish outer zones generally (as at Weipa, Qld.), are more kaolinite- and boehmite-rich. In addition, whereas the pisolite cores are generally more coarsely crystalline compared with the pale margins and intertitial matrix, they are by contrast predominantly gibbsitic with little or no boehmite. Frequently, however, particularly in the surface levels of the hardcap, the pisolite cores are completely replaced by maghemite with accessory amounts of goethite and magnetite (plus hematite instead of magnetite at Angus Cut). Thus, as opposed to the views of Hagg (1935), Basta (1957) and Takenchi and Nambu (1958), it appears that the maghemite was essentially derived through the dehydration of goethite, although the reducing action of organic matter may also have played a contributory role. Furthermore its close association with magnetite in these pisolites is not unexpected in view of their solid solution relationship (Basta 1959).


Figure 6.—Pipe-structures in hardcap zone of the Cobiac Pit profile.

Figure 7.—Pisolitic hardcap from Jarrahdale showing complex zoning of pisolites with frequent maghemite cores.

Figure 8.—Incipient zoning of bauxitised granitic fragment near the bottom of the Jarrahdale profile.

Other products of dehydration in the hardcap zones of these three profiles appear as scattered pale yellow porous patches, which stand out in marked contrast to the predominantly dark red colour of the bauxite. Here again it is possible to observe a complete sequence of change starting from the dehydration and recrystallisation of the reddish pisolites and/or matrix to coarsely crystalline gibbsite and quartz (Fig. 4), until in the final stages irregular cavities partially filled with gibbsite oolites are formed (Fig. 5). Occasionally, however, these oolites are recemented by a yellowish boehmitic matrix and the resulting cavities completely refilled. Similar occurrences of boehmite are also occasionally found at Gove, N.T.

Electron microscopy

Two clay fractions from the Jarrahdale area were examined under the electron microscope. One represented the —200 (B.S.S.) mesh fraction from the 10 to 14 feet section of the Cobiac profile (Fig.1), while the other constituted the gritty white clay immediately underlying the unconsolidated bauxite in the Jarrahdale open-cut (Fig.2).

The first sample from the Cobiac Pit consisted predominantly of hexagonal kaolinite crystals together with a little halloysite, these tubular crystals, as in Figure 9, being now partially uncurled due to dehydration. The sample was thoroughly dispersed in distilled water prior to grid preparation, but even so only trace amounts of gibbsite could be detected by electron diffraction, most of this being very fine and attached to larger kaolinite crystals. It seems probable therefore that the gibbsite crystals being larger and more equidimensional may

Figure 9.—Electron micrograph of white basal clay at Jarrahdale, showing kaolinite crystals, metahalloysite tubular crystals, and particles of amorphous gel. x 30,000.

have sedimented more rapidly in suspension than the platy kaolinite, gel particles, halloysite, fine boehmite, and goethite crystals. Other components of the clay suspension constituted irregular particles, which being non-diffracting are considered to be amorphous gel material although from infrared spectra these appear to be largely boehmitic. Boehmite crystals from aggregate diffraction patterns, however, are largely prism-shaped but are too small to yield individual diffraction patterns.

Examination of the second or white basal clay fraction from Jarrahdale showed this to be constituted essentially of partially uncurled halloysite tubules together with some kaolinite platelets, and again a small amount of amorphous gel material (Fig. 9). Infrared absorption analyses of the latter show this to be composed of equal parts of gibbsite and boehmite.

A final point concerns the nature of iron-bearing components in both the Western Australian and Malayan bauxites. Although in the highly ferruginous hardcap zones both goethite and maghemite are clearly discernible by both x-ray diffraction and using reflected light microscopy, the iron-bearing minerals in ores containing less than 10% Fe_2O_3 are characteristically poorly crystalline with resulting poor diffraction peaks comparable with boehmite.

Examinations of these ores by electron microscopy and electron diffraction have revealed that goethite and not hematite is the predominant iron-bearing mineral present, this occurring as minute often irregular specks attached to larger crystal aggregates—and particularly to the dark amorphous gel particles. Much of the ferruginous component in bauxites could occur in an essentially gel-like form but owing to its poor infrared absorption bands and thermogravimetric characteristics, which are identical with gibbsite and goethite, this is extremely difficult to examine in any detail. It is interesting however that experimental ageing of iron oxide gels at varying pH's by MacKenzie and Meldau (1959) produced only extremely fine goethite microlites in a predominantly amorphous gel, thus substantiating the writer's view that the chief iron-bearing mineral present is goethite and not hematite.

Infrared absorption spectra

As in the southeast Johore bauxites (Grubb 1965) comparisons of absorption spectra show a marked tendency for boehmite to be concentrated in the clayey matrix fractions, whereas gibbsite predominates in the harder concretions and pisolites. Again this emphasises the extremely fine nature of boehmite in these and many other bauxites.

Also of interest here is the detection of some opaline silica in the clay fractions.

Chemical Analyses

Chemical analyses of composite unscreened samples and some finer clay fractions from these were obtained gravimetrically using the tri-acid method, the alumina percentage being taken as the difference between the total R_2O_3 and the Fe_2O_3 obtained by separate titration. The results of these analyses are listed in Table 2.

The distribution of trace elements was investigated in several bauxite samples, and revealed the presence of calcium, chromium, gold, magnesium, sodium, tantalum, thorium, tin and vanadium.

Discussion

From the data presented it is evident that differences exist between the high level laterites (as exemplified by the Cobiac and Jarrahdale profiles) and the lower level Angus Cut section. The most significant of these is the higher grade and greater depth of bauxite ore in the two higher level members. In addition assuming the cumulative increase in heavy mineral content with height in these laterites to be a rough

TABLE 2

Chemical analyses of lateritic bauxite and clay from Angus, Cobiac and Jarrahdale laterite profiles of Western Australia

	Cobiac							Jarrahdale			Angus Cut		
	1	2	3	4	5	6	7	8	9	10	11	12	13
Loss on ignition	32.11	31.25	30.34	30.82	30.59	27.00	26.10	18.40	27.40	8.66	21.44	15.18	12.40
SiO_2	5.42	4.47	7.58	6.38	6.00	9.42	8.87	6.17	5.82	69.04	18.20	29.35	46.41
Fe_2O_3	4.90	10.25	6.18	6.40	11.20	9.48	11.96	26.80	14.00	0.48	11.42	13.52	0.20
TiO_2	0.20	0.70	0.60	1.20	0.29	0.20	0.20	0.80	1.00	0.10	0.75	1.16	nil
Al_2O_3	57.37	53.33	55.30	55.20	51.92	53.90	52.87	47.00	49.50	24.32	46.98	40.80	38.21
Insoluble residue	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil	n.d.	2.78

1. 0 — 4′ hardcap horizon from Cobiac profile.
2. 4′— 7′ unconsolidated earthy bauxite section from Cobiac profile.
3. 7′—10′ unconsolidated earthy bauxite section from Cobiac profile.
4. 10′—14′ unconsolidated earthy bauxite section from Cobiac profile.
5. —200 mesh (B.S.S.) " clay " fraction from the 4′—7′ earthy bauxite section. Cobiac profile.
6. —200 mesh (B.S.S.) " clay " fraction from the 7′—10′ earthy bauxite section, Cobiac profile.
7. —200 mesh (B.S.S.) " clay " fraction from the 10′—14′ earthy bauxite section, Cobiac profile.
8. Ferruginous hardcap horizon, Jarrahdale profile.
9. Unconsolidated earthy bauxite horizon, Jarrahdale profile.
10. Gritty white basal clay, Jarrahdale profile.
11. Hardcap horizon. Angus Cut profile.
12. Unconsolidated earthy bauxite. Angus Cut profile.
13. Gritty white basal clay. Angus Cut profile.

Analysts: P. L. C. Grubb and N. Philip.

index of the proportion of material the parent rock during lateritisation, it is evident from Figures 1, 2 and 3 that the proportional increase of heavy minerals with height in the high level Jarrahdale and Cobiac profiles has been far greater than in the lower level Angus Cut section. On the basis therefore that lateritisation occurred here during a single epoch (David 1950) it can be concluded that this was more intensive at higher elevations where tectonic uplift was sufficient to maintain the more rapid percolation of meteoric solutions with dissolved silica. However although tectonic uplift is apparently essential for more prolonged and intensive lateritisation, a critical balance exists, for should this uplift be too rapid the region would be denuded of its surface bauxite horizon through erosion, the ratio of surface run-off to percolating meteoric water increased, and finally the rate of percolation would be too rapid to permit maximum solution of silica and iron from the parent rock. On the other hand if tectonic uplift was too slow the rate of meteoric water percolation would be decreased and because of the resulting high water table level either surface rekaolinisation would occur or in the case of a strongly seasonal climate a hard surface duricrust could form, which would impose an effective barrier to further bauxitisation. These optimum conditions must evidently have been met during the epeierogenic uplift of the Darling Ranges although conditions appear to have been less favourable in the Greenbushes area.

Among the remaining factors influencing the intensive lateritisation within the Darling Ranges belt were its proximity to the sea with relatively high precipitation thus supporting a relatively dense tall forested vegetation which produced a high ratio of meteoric water percolation to surface run-off. Moreover as apparent at Gove, N.T. it is also probable that the total extraction of silica by vegetation constitutes a significant factor in lateritisation. Parent rock has also played a noteworthy role in the Darling Ranges, although as shown also by Loughnan and Bayliss (1961) the overall composition is of little importance. Instead its susceptibility to bauxitisation is determined by several interrelated factors. The chief of these are texture and structure, for while the rock must be relatively fine grained, so as to present the maximum intercrystalline surface area for solution, it must also retain sufficient rigidity during lateritisation so that the percolation rate of meteoric solutions continue unaltered. A third factor is the interrelated mineral and chemical composition for although under otherwise ideal conditions bauxitisation may attack almost any rock type, it is evident that certain mineral assemblages are more readily attacked than others. The explanation of this is not entirely understood but for several reasons appears to be physicochemical with little dependence on overall chemical composition. In the Darling Ranges, the predominant medium to coarse grained granitic rock types clearly meet the majority of these requirements, although the coarser texture of the Angus Cut granite parent rock would explain the more siliceous composition of the resulting bauxite.

The differential segregation of boehmite and gibbsite in these profiles follows closely on similar observations made at Gove, N.T. and in Gippsland, Victoria. Thus, as described earlier (Grubb 1965) it is considered that boehmite constitutes one of the earliest bauxitisation products and that this is progressively replaced by gibbsite during the progressive fall in the water table level. It is interesting to note here that boehmite has been detected as the primary aluminium hydrate after artificial leaching of albite in water under various partial pressures of CO_2 (Lagache 1965). The occasional increases in boehmite content in the uppermost two or three feet of the profile, on the other hand, may be accounted for both by increased desiccation and aeration. Besides, with a relatively thick vegetational cover, the meteoric water near the surface would contain a comparatively high proportion of humic acids and dissolved CO_2, and this would play a dual role. Firstly, as shown experimentally by Keith (1959), the transformation of boehmite to gibbsite can be arrested by saturation with CO_2. Secondly, Sechrist (1963) has demonstrated that the presence of excess CO_2 may increase the surface evaporation rate by 30% and this is quite independent of other factors. However, the retention of only a small proportion of boehmite in the uppermost 2 feet of the Jarrahdale opencut profile is not fully understood but suggests a stationary water table level for a prolonged period with the replacement of boehmite by gibbsite going almost to completion except in the surface horizons where the vegetational cover may have been less dense.

Some comparisons with other Australian bauxite deposits

As already indicated, of the deposits already familiar to the writer those situated at Gove (N.T.) bear the closest resemblance to the Darling Ranges bauxite. In their field relations, although several divergencies exist, all three sections described here from the Darling Ranges are almost identical in lithological succession to the true residual sections situated a mile inland from the coastline of the Gove Peninsula. The chief differences apart from the chemical and mineral composition are that the Darling Ranges laterite possesses a prominent hardcap horizon and appears to have been slightly more eroded. It is uncertain as yet however whether any recemented colluvial horizons, as are common at Gove, occur in the Darling Ranges, none having so far been observed by the writer.

In boehmite content the Darling Ranges are closer to the Weipa deposits than those of Gove, but lithologically they appear to be somewhat different.

No similarity apart from their relatively high monohydrate content exists between the Gippsland deposits and those of the Darling Ranges. This is not unexpected however in view of the former being derived from a basaltic parent rock, having experienced a different tectonic history, and being now buried under carbonaceous clay horizons and Tertiary sands.